1. IC6.1: Introduction to the Top-Down Methodology

Instructor Notes: Welcome to IC 6 lesson 1 Introduction to the Top-Down Methodology. This lesson is 42 slides long and will take approximately 35 minutes to complete.

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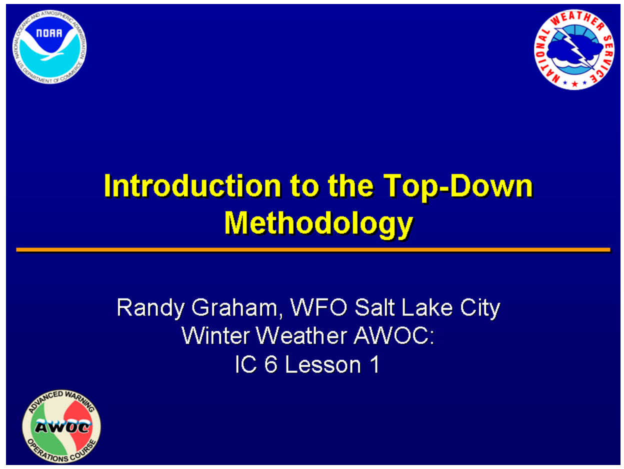

2. What is the Purpose of this Lesson?

Instructor Notes: This is the 1st lesson in IC6. This lesson will cover the Top-Down methodology for determining precipitation type. Much of the material in this module is built off of work compiled by Dan Baumgardt (SOO, LaCrosse WI). The motivation for this lesson is to enable forecasters to intelligently assess observed and model soundings with respect to the determination of precipitation type. The lesson will examine the reasoning behind the different concepts utilized in the top-down methodology. Ultimately, the lesson will allow us to assess observed and model soundings in a manner which will assist in the determination of precipitation type in an operational setting. The speaker notes for this lesson will contain additional detail above beyond that which on the slides and may serve as a good reference for review.

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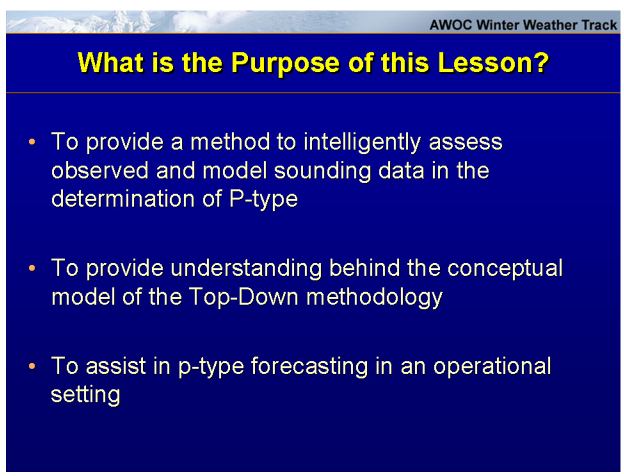

3. Outline

Instructor Notes: This lesson is divided into six sections. The first section will provide a brief overview of the learning and performance objectives for this lesson. The final five sections are dedicated to ice nuclei and activation temperatures, warm layer impacts, surface layer considerations and, finally, a complete overview of the top-down methodology.

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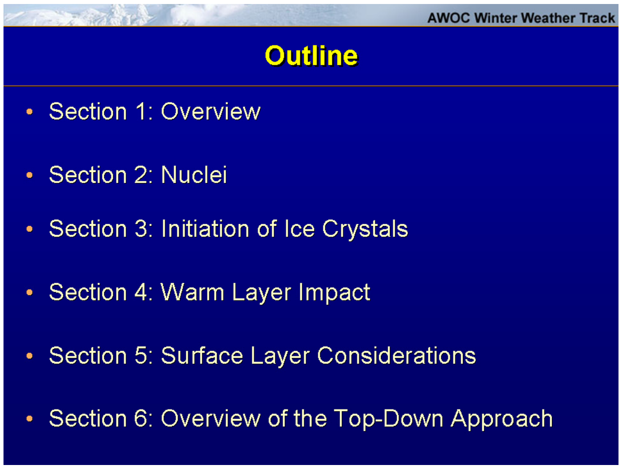

4. Learning Objectives

Instructor Notes: The primary learning objective for this lesson is to understand the conceptual reasoning behind the top-down methodology. After completion of this module you should be able to identify activation temperatures for ice nuclei, be able to assess the impact of a warm layer, as well as understand surface layer considerations. You should also be able to describe the impact of other factors that impact the resultant precipitation type such as wet-bulb temperatures, the seeder-feeder mechanism, and precipitation intensity.

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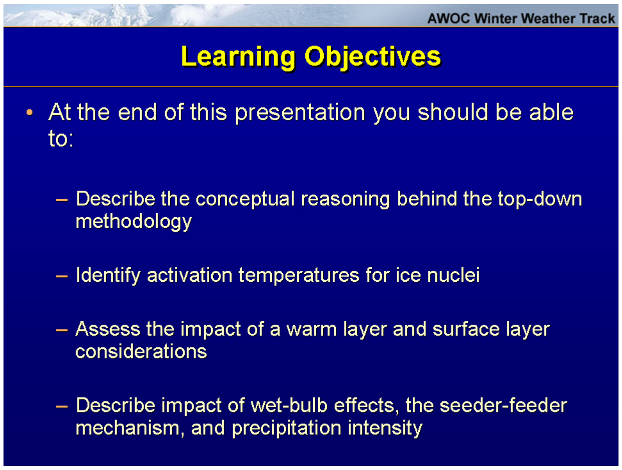

5. Performance Objectives

Instructor Notes: The ultimate success of the lesson driven by impacting performance in an operational setting. At the end of this lesson you will be able to successfully apply the Top-Down methodology in forecast operations. This includes assessing the potential for heterogeneous nucleation. In other words you will be able to interrogate a sounding and determine the likelihood that a cloud in the environment represented by the sounding will be able to support heterogeneous nucleation. You also will be able to assess the impact of elevated warm layers. For example, if an ice crystal is entering an elevated warm layer will the layer be strong enough to partially or completely melt the ice crystal as it falls through the layer? Additionally, you will be able to interrogate the impact of the near surface layer on the resultant precipitation type in an operational setting. This will include the ability to assess the impact that wet bulb effects and precipitation intensity may have on the precipitation type.

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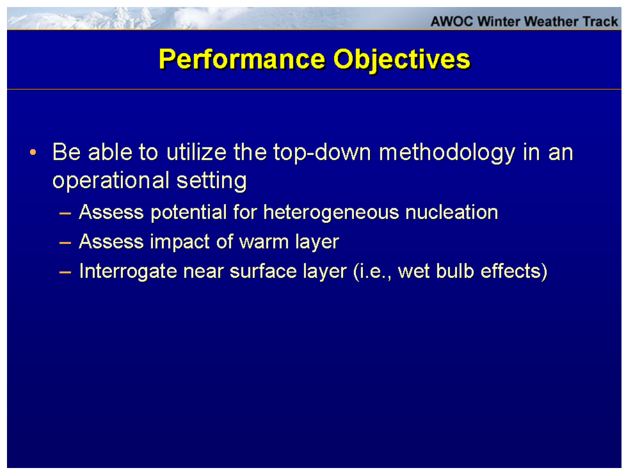

6. Why Use the Top-Down Methodology?

Instructor Notes: So, why should we use the top-down methodology? When low resolution models were the only form of guidance available forecasters were forced to rely on standard level temperatures and deep layer thickness rules of thumb to assess precipitation type in a forecast environment. Since the advent of gridded data sets we now have the opportunity to more robustly assess the evolution of precipitation particles from their initial development through their descent to the surface. The high resolution data sets that are available today allow us the opportunity to assess the potential for a variety of precipitation types quite readily through the utilization of BUFR profiles of temperature and moisture. The top-down methodology employs microphysical concepts to insinuate the initial phase of the precipitation particles and then attempts to ascertain the evolution of the hydrometeors as they descend through the lower troposphere. The top-down methodology can be applied to both observed and forecast soundings. Of course, when looking at forecast profiles produced by NWP models the forecaster must consider the accuracy of the model before one can reliably utilize the forecast sounding to assess precipitation type. If the model has a poor handle on the large scale features then the resulting thermal and moisture profiles may be inaccurate and will likely not yield a quality p-type forecast. Also, keep in mind that higher resolution model data may have the right idea, but if, for example, the intense forcing associated with a mesoscale snow band in the guidance is misplaced the vertical profiles may be inaccurate as well. As with any assessment of NWP guidance it is critical that forecasters assess the performance of the model to determine the quality of the NWP forecast. The application of the top-down methodology discussed in this lesson and the microphysical concepts that are the root of the method are readily understood and can easily be applied in an operational setting. In addition, not only do these microphysical concepts tell us something about the precipitation type we can also utilize these concepts to glean information about the potential precipitation intensity for a pending precipitation event which will be covered in subsequent AWOC lessons.

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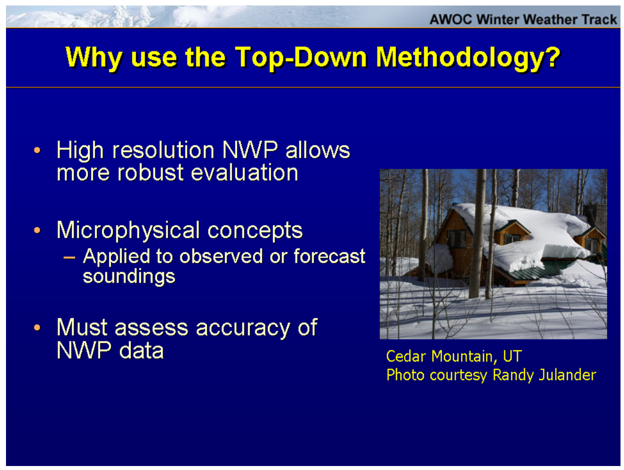

7. This the Core of the Top-Down Methodology

Instructor Notes: To utilize the Top-Down methodology we, as forecasters, have much to consider. However, a good understanding of the concepts upon which the methodology is built will enable us to robustly interrogate both observed and model soundings in anticipation of a variety of precipitation types. The concept of the top-down methodology intuitively begins with an assessment of the initial or predominant hydrometeor state in the cloud. In this module we will discuss how to assess the potential that a cloud contains ice crystals versus one that is dominated by super-cooled water droplets. After assessing the likelihood of ice crystals in the cloud the top-down methodology leads us interrogate any elevated warm layers that may be present. That is, assuming that we have ice crystals entering an elevated warm layer, how warm or deep does it need to be to completely melt the hydrometeors? At what point is a warm layer so shallow or weak that it has little impact on the resultant hydrometeor state? Finally, we will assess the near surface layer to determine if there is a deep enough warm layer to melt ice crystals, or if there is a cold wedge strong enough to re-freeze hydrometeors, possibly melted in an elevated warm layer, into ice pellets. Other concepts that must be considered include the seeder-feeder mechanism through which ice crystals can be introduced into a cloud that otherwise would not support heterogeneous nucleation. One must also consider wet-bulb effects which can have a significant impact on the ultimate precipitation type if temperatures fall rapidly due to evaporative cooling as hydrometeors descend through a relatively dry layer in the troposphere. Lastly, the impact of precipitation intensity on precipitation type must be considered.

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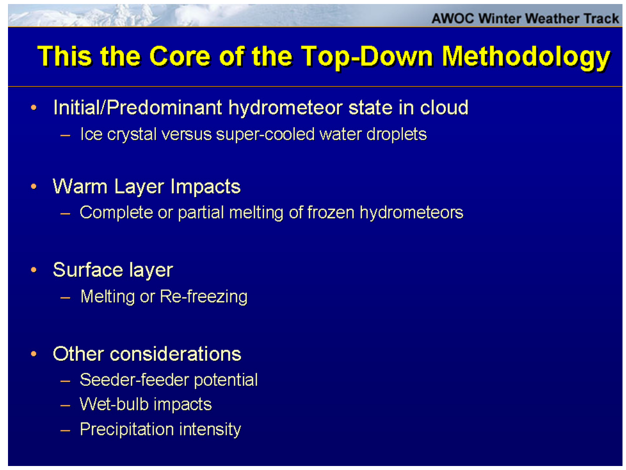

8. What is the Role of Condensation Nuclei?

Instructor Notes: Of all of the particulates in the air only 5-10% of these can act as Cloud Condensation Nuclei (CCN). These are particulates which support the growth of cloud droplets on their surface. Of the available CCNs only a very small number can act as ice nuclei thereby supporting the growth of ice crystals. The odds that a CCN can act as an ice nuclei increase as the temperature decreases and the relative humidity increases. Therefore, heterogeneous nucleation is more likely to occur in the coldest regions of a cloud, which is typically in the upper reaches of the cloud.

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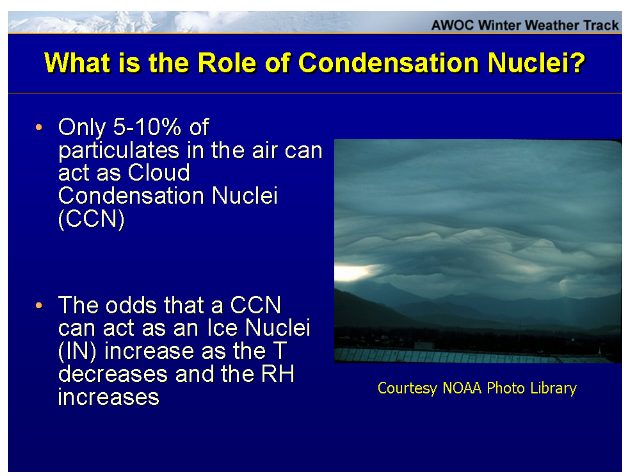

9. Initiation of Crystal Growth

Instructor Notes: Ice Nuclei (IN) are available in the atmosphere at much lower concentrations than are Cloud Condensation Nuclei. IN are hygroscopic molecules, meaning that they attract water. According to Rogers (1979), the hexagonal lattice structure which comprises IN resembles that of natural ice. IN, however, do not become active until the environment in which they are present reaches a certain temperature threshold (assuming saturation with respect to ice). As we shall discuss shortly, the temperature at which these IN become active varies for the different types of IN. One certainty is that as the temperature drops, more IN become available to initiate ice crystal formation. In other words, the concentration of active IN rises as the temperature drops. The term 'Heterogeneous Nucleation' simply refers to crystal initiation or activation on the surface of an ice nucleus. Any liquid drop freezing onto an IN or the process of ice forming on an IN is referred to as heterogeneous nucleation. Essentially, this is the initiation of the ice crystal growth process. Homogeneous (or spontaneous) nucleation occurs when there is no surface for the drop or ice to initially form on. An ice embryo of a critical size (one that won't break up) is formed by the chance aggregation of a sufficient number of water molecules. This occurs around - 36 degrees C to -40 degrees C.

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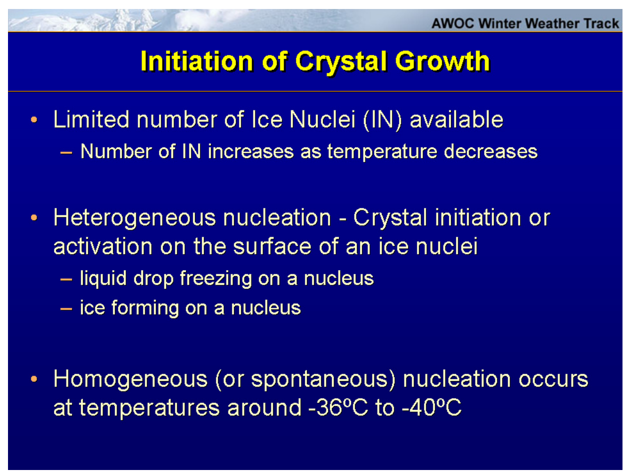

10. What Produces Heterogeneous Nucleation?

Instructor Notes: Though bodies of liquid water freeze when their temperatures reach slightly below 0 degrees C, water droplets in clouds behave quite differently. Observations in clouds have shown that at -10 degrees C it is possible to have only 1 ice crystal per 1 million liquid water droplets. Even at -20 degrees C, the ratio of ice to liquid can be less than 50%. However, some operational studies have noted a predominance of ice in clouds approaching -20 degrees C. In laboratory experiments, cloud temperatures can reach -40 degrees C before clouds are comprised of all ice crystals (Pruppacher and Klett, 1979). Water droplets that are found in temperatures below freezing are referred to as supercooled. Regions of a cloud transformed to ice crystals, where the cloud is saturated with respect to ice, are said to be glaciated. Generally, a cloud with temperature warmer than around -10 degrees C will typically be primarily composed of supercooled water droplets. Clouds with temperatures between -10 and -20 degrees C will exhibit a mixed phase of supercooled water droplets and ice crystals. Clouds colder than -20 degrees C will be composed primarily of ice. What we want to address when we are looking at saturated layers from a p-type perspective is the likelihood that the corresponding cloud contains ice crystals.

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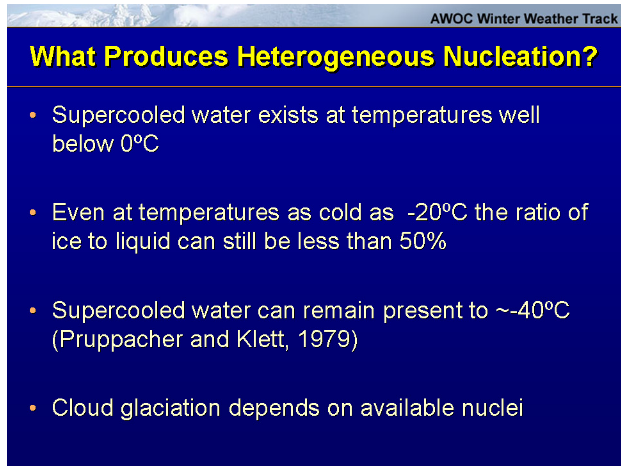

11. When Do Ice Nuclei Activate?

Instructor Notes: IN have a structure similar to ice which enables ice to form readily on their surface. Different types of IN have different activation temperatures. Leaf bacteria which are found in decaying leaf matter can support ice at temperatures as warm as approximately -3 degrees C. Clay materials can be the dominant IN available in some portions of the country such as the Midwest. One of these common clay materials, Kaolinite, has an activation temperature of -9 degrees C. Areas near oceans may have an abundance of sodium chloride available which activates at -8 degrees C. So, depending on the particulates available crystal initiation will occur at different temperatures. While information on available IN is not readily available on a real-time basis a general baseline can be used regionally based on what is believed to be the most prevalent IN in that region. For example, over much of the Great Plains, Great Lakes, the Ohio Valley one might assume that clays such as Kaolinite are the most prevalent IN with activation temperatures at -9 degrees C. Areas in proximity to the ocean might assume that sodium chloride would be abundant with onshore flow resulting in activation temperatures slightly warmer than -10 degrees C. Operationally, we cannot draw hard and fast rules based on these numbers as we are uncertain of the type and distribution of ice nuclei available in a given cloud deck. However, we can apply this in general in that as clouds are present at colder temperatures the likelihood of ice initiation increases.

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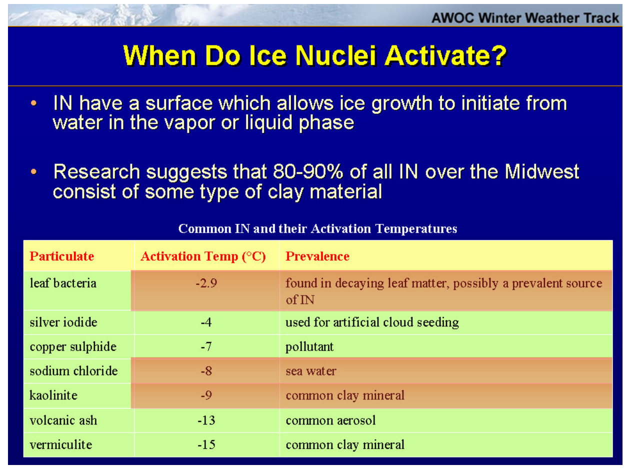

12. All-Liquid Cloud vs. Clouds Containing Ice

Instructor Notes: Given the activation temperatures that we discussed on the previous slide one can make some inferences as to the likelihood of ice crystals being available in a cloud given the cloud top temperatures. The chart on the right gives an idea of the potential for ice crystals to be contained within a cloud. The y-axis is the percentage of All-liquid clouds while the x-axis is the coldest temperature within the cloud layer. As you can see if the coldest temperature within the cloud layer is -5 degrees C there is about an 80% chance that the cloud will consist entirely of super-cooled water. If the coldest temperature with the cloud layer is -10 degrees C there is a 50-60% chance that the cloud will contain ice. By the time the cloud cools to -15 degrees C there is about an 80% chance that the cloud will contain ice crystals. Operationally, it has been found that the likelihood of ice in a cloud increases substantially around -10 degrees C and this is good break point for assuming that there are ice crystals contained with the cloud. If the coldest temperatures within the cloud layer are warmer than -10 degrees C one can assume that there is a higher probability that the cloud is composed entirely of supercooled water droplets (assuming no introduction of ice crystals from an outside source such as the seeder-feeder mechanism). By the time cloud temperatures drop to -12 degrees C it is quite likely that ice crystals are present in the cloud. Note that these values are not absolute, (i.e., deterministic) it may be best to think in probabilistic terms. If you examine the chart on this slide you will see that there is a population of events in which ice crystals are present and the coldest temperature in the cloud layer is warmer than -10 degrees C. As a forecaster we should think of this in probabilities. In other words, the colder the layer in which the cloud exists the more likely you are to have ice crystals present. Due to the presence of sea salt nuclei for near ocean sites this ‘cutoff’ may need to be increased a bit although maybe not 2-3 degrees C as previously thought.

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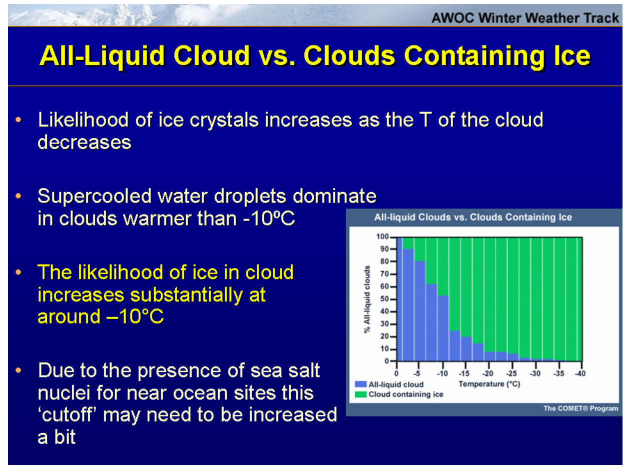

13. Ice in Clouds?

Instructor Notes: Operationally there are several ways to assess the potential for heterogeneous in a given cloud layer. Looking at observed soundings is an excellent way to assess the state of the troposphere in the vicinity of the upper air site at 0000 and 1200 UTC. One could also examine BUFR data from operational forecast models utilizing AWIPS or a software package such as BUFKIT to assess whether or not the saturation extends to temperatures cold enough to support the initiation of ice crystals. Note that models reach the NWP equivalent of a saturated state at different levels of relative humidity. You could also assess the depth of the saturated conditions by looking at time heights at a variety of locations. To assess whether a given cloud deck has glaciated in a nowcast mode we can look to see if IR cloud top temperatures are -10 degrees C or colder. For example the IR image curve displayed here exhibits yellow cloud tops when the cloud top temperatures are between zero and -8 degrees C transitioning to white when ice becomes likely in the cloud at temperatures -12 to -15 degrees C and ultimately to black when ice should definitely be present in the clouds at temperatures colder than -20 degrees C. A curve such as this can help forecasters assess the likelihood of the presence of ice in a given area. For example, cloud top temperatures across much of northern Indiana and extreme southern Michigan are in the zero to -8 degrees C range and are not likely to contain ice. However, the lake band extending to the southeast off of Lake Michigan is clearly glaciated as are cloud tops across most of northern lower Michigan extending eastward into New York.

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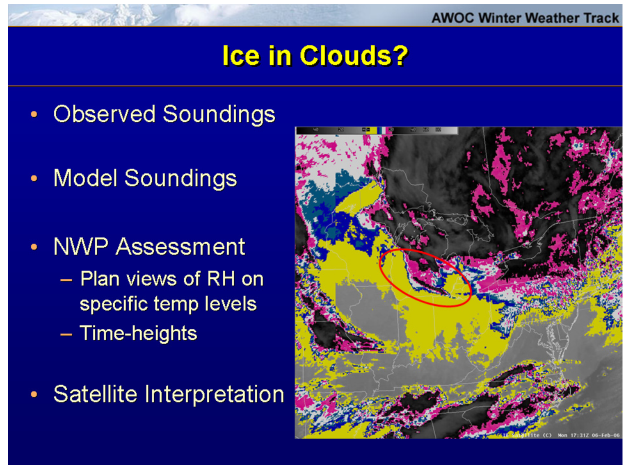
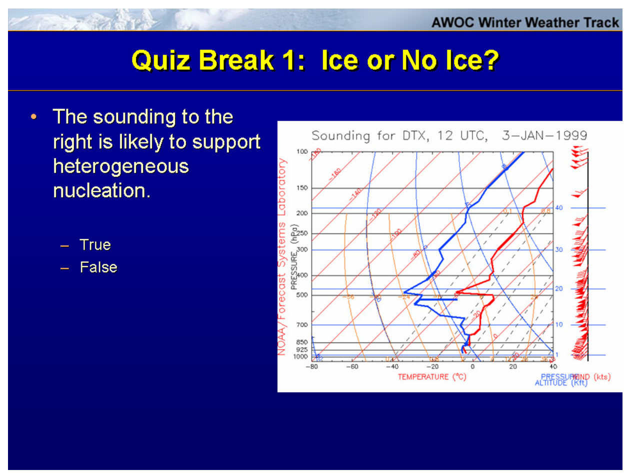


14. Quiz Break 1: Ice or No Ice?

Instructor Notes: The sounding to the right is likely to support heterogeneous nucleation. True or False? Click on the Next button (highlighting right arrow) to advance when you are ready for the answer.

Student Notes:



15. Quiz Break 1: Ice or No Ice?

Instructor Notes: The sounding to the right is likely to support heterogeneous nucleation because the sounding clearly exhibits saturation to temperatures colder than -10C. So the answer is True.

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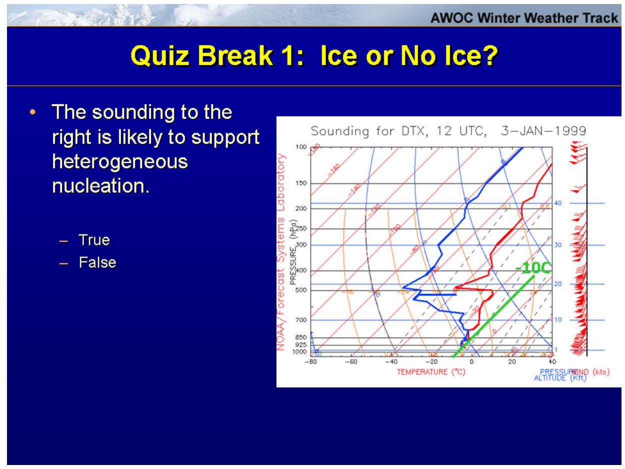

16. Quiz Break 2: Ice or No Ice?

Instructor Notes: Another True or False. Given the material that we have covered with respect to heterogeneous nucleation the sounding to the right is likely to support the initiation of ice crystals. Click on the Next button when you are ready to advance to the next slide and hear the answer.

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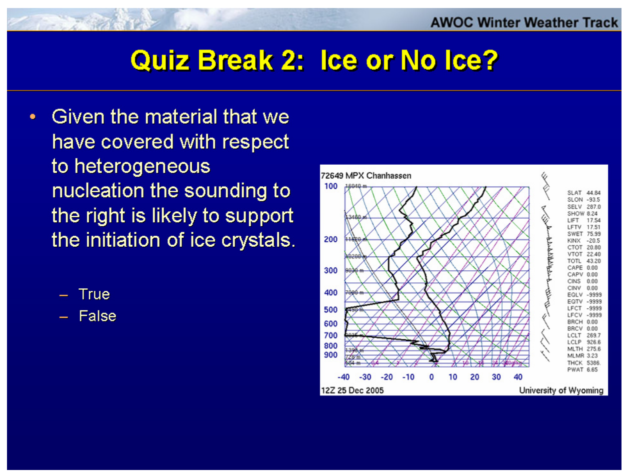

17. Quiz Break 2: Ice or No Ice?

Instructor Notes: In this case, the sounding is only saturated to around -5 degrees C, so there is only around a 20% chance that ice crystals will be present. So the answer is false.

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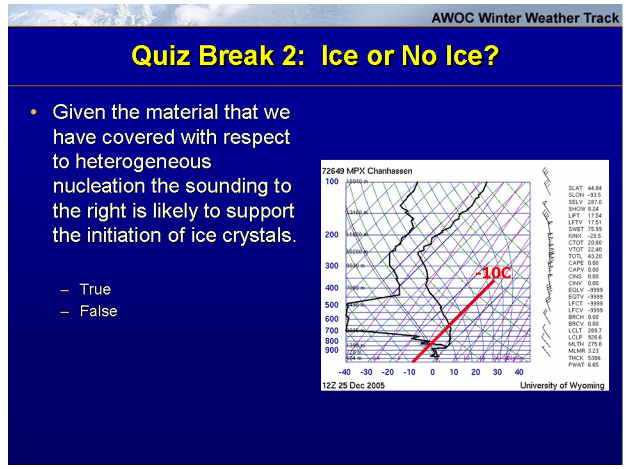

18. Breaking the “Rules”…

Instructor Notes: As we have discussed previously, we should think of the likelihood of heterogeneous nucleation in probabilistic terms. This an example from December 2005 where snow fell out of a cloud deck which was not saturated to temperatures of -10 degrees C or colder. The area of interest is here in central and southern Minnesota. The 1200 UTC image indicates light snow in several locations including Minneapolis. A look at area observations at 1100 UTC, around sounding release time, indicated that numerous observation sites in this area were reporting light precipitation, with the vast majority reporting light snow.   Looking at the corresponding sounding released by the Chanhassen WFO we can see that saturation did not extend to temperatures of -10 degrees C or colder. In fact, the sounding was only saturated to around -6 degrees C. This example is shown to illustrate that even though the likelihood of heterogeneous nucleation increases markedly around -10 degrees C that there is a population of events where ice is initiated at temperatures warmer than -10 degrees C and a population of events where ice is not present with cloud temperatures colder than -10 degrees C. So, while in the majority of instances the concept of ice crystal initiation around -10 degrees C is perfectly valid there will be outlier events due to the complexity of ice nuclei and the nucleation process. For example, clay material that has previously acted as ice nuclei, but no longer has ice present on its surface will re-activate at temperatures (maybe 3-5 degrees warmer) than it initially would have. Operationally, there is no way to determine this and while the -10 degrees C threshold is a valuable tool for assessing the likelihood of ice crystals in a cloud there will be outlier events that deviate from this.

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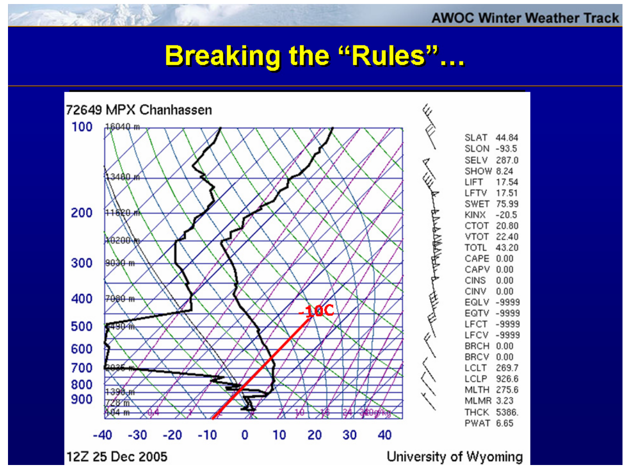

19. Introducing Ice from an Outside Source (The Seeder-Feeder Mechanism)

Instructor Notes: There is a method through which warmer clouds that otherwise would not contain ice crystals can support ice crystal development. If ice is introduced into a cloud composed entirely of supercooled water droplets the ice crystals will grow preferentially over the supercooled water droplets because the saturation vapor pressure is greater with respect to ice crystals than it is with respect to supercooled water droplets. For example, consider a cloud with cloud-top temperatures warmer than -10 degrees C. Given the IN activation temperatures we have seen this cloud is likely not in an environment supportive of heterogeneous nucleation. In the example to the right we see a theoretical low level cloud deck that consists of supercooled water droplets and no ice crystals. If there exists a cloud layer in a cooler environment above this lower cloud deck and this higher cloud layer contains ice crystals it could 'seed' the lower cloud layer. This occurs when the crystals fall from the higher cloud deck through the saturated cloud layer below. This is called the "seeder-feeder" process. For the "seeder-feeder" process to be a concern the maximum separation between the two cloud layers should around be 1500m (5000 feet) or less. Also, it should be noted that larger denser crystals and are more likely to survive descent through a dry layer than are small less dense crystals. Crystals are also more likely to survive a descent through a moist environment as less sublimation will occur than in a dry environment. One way to assess the potential for the seeder-feeder process to occur is to look at the VWP to determine the separation between cloud layers. Again cloud top temperatures in IR imagery can also be of assistance. If the cloud decks are not separated by a substantial depth a mid level cloud deck can easily seed a lower cloud deck as it moves over the top. This can change a freezing precipitation event to all snow n as the mid cloud deck moves through the area seeding the lower warmer cloud with ice crystals.

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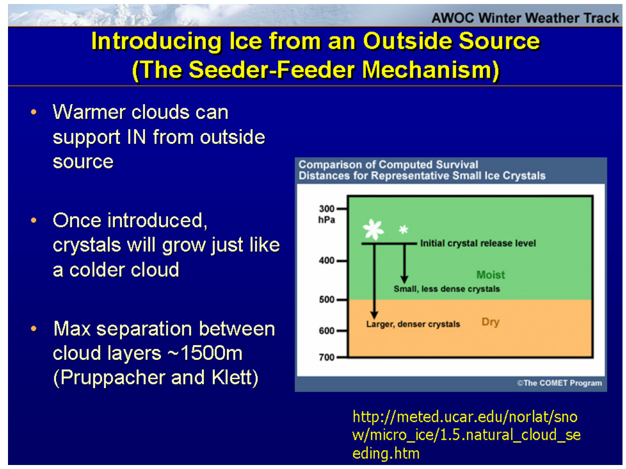

20. What is Impact of an Elevated Warm Layer?

Instructor Notes: After assessing the vertical profile for presence of ice crystals in the upper reaches of the cloud layer we must look for, and assess, elevated warm layers. Elevated warm layers are generally associated with warm fronts and, if present, can play a critical role in the ultimate precipitation type at the surface. When considering the elevated warm layer it is useful to examine both the maximum temperature contained within the layer as well as its depth. Rauber et al (2001) found that there was a strong correlation between the depth of the warm layer and the layer maximum temperature for soundings east of the Rocky Mountains. In most cases, it is easier to assess the maximum temperatures in a warm layer than it is to anticipate the depth of a warm layer. Therefore, we will focus more on the maximum temperature in the warm layer as it relates to the top-down methodology of anticipating p-type. Still, as forecasters, we must be cognizant of the shape of the warm layer in question. The top-down methodology assumes a more classic warm wedge (like a triangle on its side) when assessing the impact of a given warm layer on the p-type. If the warm layer deviates from this assumption the values displayed on this table may not be entirely representative. Although there will be outliers the values displayed here will point to the most probable outcome for a given warm layer. If the warm wedge is a deep (say, 5000 feet) nearly isothermal layer with a max temperature of +2 degrees C it will have a different impact than if it is a shallow (say, 2000 feet) warm wedge with a maximum temperature of +2 degrees C. Although Rauber et al. found a strong correlation between max temperature in the warm layer and the depth of the warm layer we still need to be cognizant of outliers. The table on this slide exhibits the impact that various warm layer maximum temperatures will have on the resultant precipitation type for instances where ice is introduced into the top of the warm layer as well as those cases where supercooled water is introduced into the top of the warm layer. It should be noted that the melting of ice crystals as they fall through an elevated or surface based warm layer is impacted by the size, density and structure of ice crystals. Other factors that play a role in the melting include crystal fall velocity (which is related to size & shape of the crystals) as well as the temperature, depth, lapse rate, and relative humidity of warm layer. Despite the wide range of impacts associated with the efficiency of the melting process we can make some general statements about the most likely outcome of the melting process based on the maximum temperature in the warm layer. Note that these are simply the most likely outcomes. A warm layer with a maximum temperature of less than 1 degrees C will not be warm enough to melt snow or ice falling though this layer (unless it is abnormally deep). Therefore, the precipitation type would be expected to remain as snow as very limited, if any, melting would occur. For warm layers that have maximum temperatures of 1 degrees C to 3 degrees C melting will occur, but the complete melting of ice crystals is unlikely. As hydrometeors exit the warm layer aloft and enter a surface based cold layer many, if not all, of the partially melted hydrometeors will refreeze. Correspondingly, when the maximum temperature in the warm layer is in the 1-2 degrees C range a mix of ice pellets and snow is likely. For warm layers supporting temperatures closer to 3 degrees C ice pellets will be the most likely precipitation type. Finally, If the maximum temperature in the warm layer is greater than +3 degrees C we would expect complete melting of hydrometeors as they fall through this elevated warm wedge resulting freezing rain or freezing drizzle at the surface (assuming a surface based cold layer). Even with complete melting ice pellets would be possible at the surface if the surface based cold layer was strong enough, say colder than -10 degrees C, to completely re-freeze the hydrometeors. Finally, looking at the column on the right hand side we consider the case where no ice is introduced into the top of this warm layer. If this is the case and there is a surface based cold layer one would anticipate freezing rain or freezing drizzle. If the surface layer was above freezing then we would expect rain or drizzle. This table is based on the maximum temperature in the warm layer. Please be cognizant that if this warm layer is not saturated then the impact of the warm layer will most likely be as indicated in the table above in reference to the maximum temperature of the layer at the initial onset of precipitation. However, if it is not saturated then the profile in the warm layer will cool to the wet-bulb temperature which may have a significant impact on the resulting precipitation-type.

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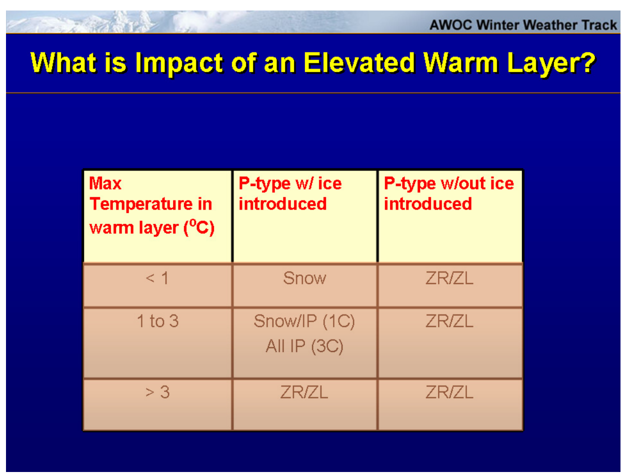

Max Temperature in warm layer (^oC)	P-type w/ ice introduced	P-type w/out ice introduced
< 1	Snow	ZR/ZL
1 to 3	Snow/IP (1C) All IP (3C)	ZR/ZL
> 3	ZR/ZL	ZR/ZL

21. Wet Bulb Effects

Instructor Notes: Now let's take a graphical look at the impact of the warm wedge utilizing an applet developed by Tom Whittaker at the University of Wisconsin-Madison. The applet is based on concepts presented by Dan Baumgardt (SOO LaCrosse WI). Note that in this applet the red line is the dry bulb temperature and the black line is the wet-bulb temperature. In this first example, I will set the maximum temperature in the warm layer to +4.5 degrees C. Note that as ice crystals enter this warm layer they completely melt and with sub-freezing surface temperatures we have a freezing rain event underway. However, if I change the maximum dry-bulb temperature (and wet-bulb temperature) in the warm layer to +1.5 degrees C we will have a scenario in which partial melting occurs. As indicated by the table on the previous slide when the maximum temperature in an elevated warm layer is between +1C and +3 degrees C and we have ice crystals entering that layer we can anticipate a mix of snow and ice pellets. Finally, if we set the max temperature in the warm layer to say +.3 degrees C the warm wedge is not strong enough to substantially melt the ice crystals and the precipitation type remains in the form of snow.

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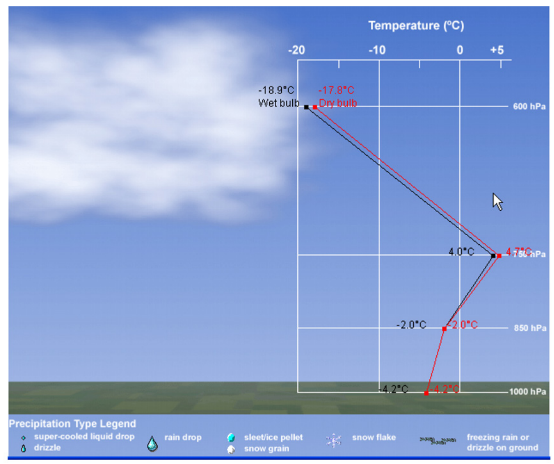
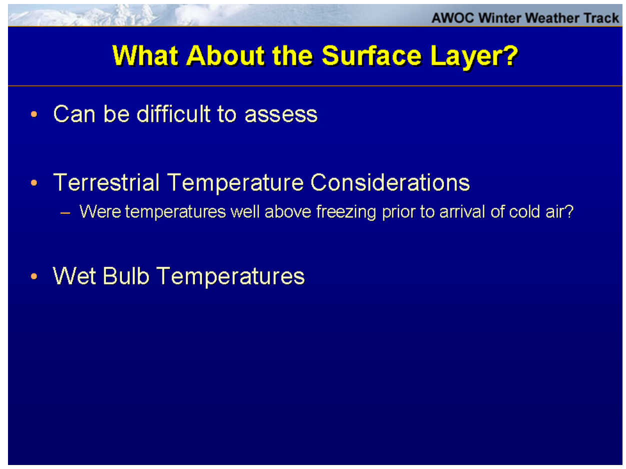


22. What About the Surface Layer?

Instructor Notes: The final region to consider when utilizing the top-down methodology is the surface-based layer. In some cases this can be the most challenging layer to assess in an operational environment. This is particularly true considering that NWP models struggle more in the boundary layer (e.g., with respect to temperatures) than they do aloft. One must consider the terrestrial temperature when anticipating freezing rain or freezing drizzle. For example, if the terrestrial temperature was above freezing before the arrival of cold air and precipitation, particularly if it had been above freezing for a considerable amount of time, surface temperatures may not be initially be cold enough for water to freeze on contact. This is something that we must keep in mind when considering freezing precipitation following periods of above-freezing temperatures. Another consideration is the wet-bulb temperature in the surface layer. The wet bulb temperature is the final temperature that an air parcel will attain after saturation is reached. The wet bulb temperature can be especially useful for distinguishing between liquid and frozen precipitation. It plays a significant role in determining the resultant precipitation type and anticipating wet-bulb impacts is especially important when dealing with sub-cloud layers that are dry at the onset of precipitation.

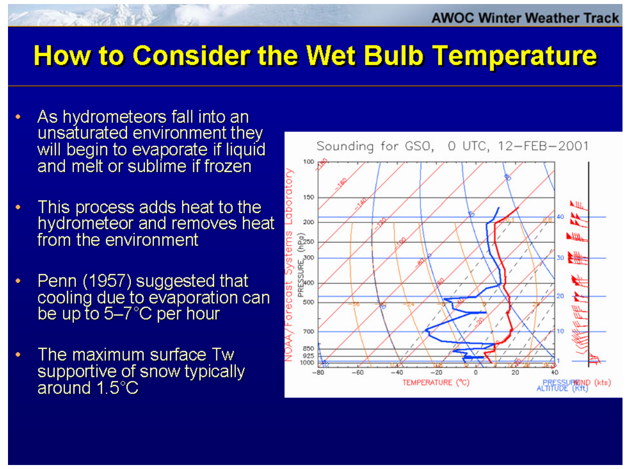
Student Notes:



23. How to Consider the Wet Bulb Temperature

Instructor Notes: The wet-bulb temperature (Tw) represents the temperature that a given parcel will attain as saturation is achieved. The wet-bulb temperature is an important consideration when attempting to distinguish between liquid and frozen precipitation. As hydrometeors fall into an unsaturated environment they will begin to evaporate if liquid and melt or sublime if frozen. This process adds heat to the hydrometeor and removes heat from the environment, while also adding water vapor to the environment, causing the temperature to drop while the dewpoint rises with both values moving towards the wet- bulb temperature (Tw). Penn (1957) suggested that cooling due to evaporation can be as much as 5-7 degrees per hour, so wet-bulb affects can obviously be quite significant. When assessing an observed or model sounding we should consider how much cooling may occur if hydrometeors were to fall into an unsaturated layer in the profile. Wet-bulb considerations are also important to consider at the surface when anticipating precipitation type. If the wet-bulb temperature is > 1 degrees C for a depth of at least 300 m above the surface ice crystals will likely completely melt and rain is the most likely p-type. If the surface wet-bulb temperature is around 1.5 degrees C or greater then the precipitation type will likely be rain, in other words the maximum surface wet-bulb temperature supportive of snow is around 1.5 degrees C.

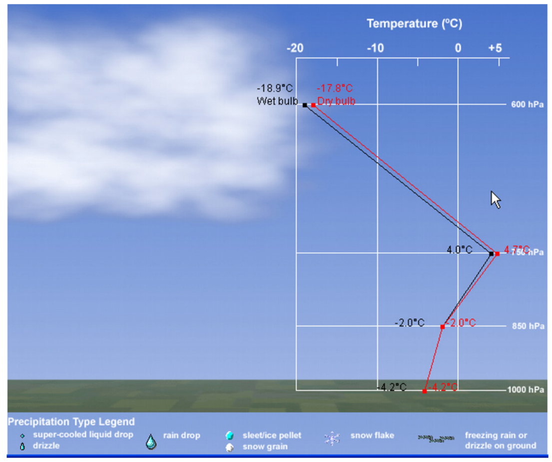
Student Notes:



24. Warm Layer Effects

Instructor Notes: As an example, consider this profile where at the 750 mb level the dry-bulb T is ~4.5 degrees C and the Tw is –0.5 degrees C. Snow falling into this layer will initially be subject to melting. With time evaporation and sublimation will lower the temperature of this level to the wet-bulb temperature. Once the layer is completely saturated the temperature at 750 mb will equal the initial wet-bulb temperature. So, initially the hydrometeors will completely melt as they fall through the warm wedge as the maximum temperature in the warm layer is greater than +3 degrees C. In this scenario, with sub-freezing surface temperatures, we would have an initial precipitation type of freezing rain. Over time, as the layer cools, we will transition to a mix of precipitation types in the form of ice pellets and snow and finally as the maximum temperature in the warm wedge approaches the wet-bulb temperature, which is sub-freezing, the precipitation will remain in the form of snow. It is important to note that you cannot simply assess the wet-bulb temperature at 750 mb to determine the precipitation type in this instance. At the onset of precipitation, knowledge of the maximum temperature in this warm layer is critical to anticipate the degree of melting that will occur as hydrometeors descend through this layer. So, the maximum temperature in this layer is important at the onset of precipitation. With time the temperature migrates towards the wet bulb temperature at which point the wet bulb temperature is the determining factor in precipitation type. Also, it should be noted that precipitation intensity plays a role in the impact of the maximum temperature of a layer. If the precipitation rate is heavy the maximum temperature will be important for a shorter duration as the ambient air temperature will cool to the wet bulb temperature more quickly.

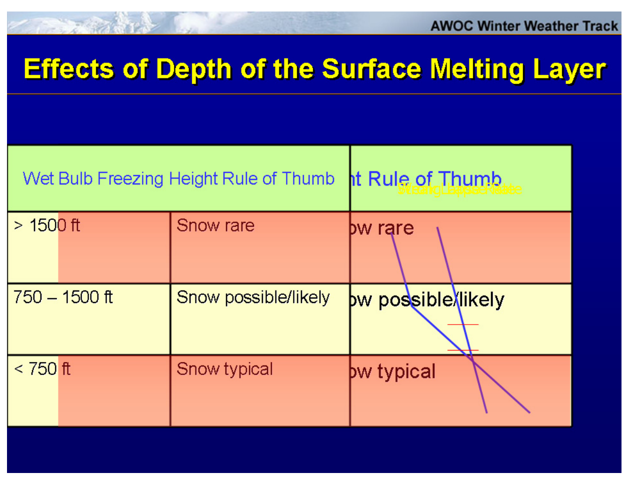
Student Notes:



25. Effects of Depth of the Surface Melting Layer

Instructor Notes: When assessing a surface based warm layer one must consider the depth of the warm layer to determine if ice crystals entering this layer will melt or remain largely frozen. The depth of above freezing air that is required to melt snowflakes typically varies from around 750 feet to around 1500 feet. Generally, if the warm layer is deeper than 1500 feet it will be deep enough to melt the ice crystals and if it is shallower than approximately 750 feet it will typically not be deep enough to completely melt the ice crystals. The depth varies depending on the mass of the snowflakes and the lapse rate in the melting layer. For example, when the lapse rate is small the melting layer is weak and it would require a greater depth of above freezing air to melt the ice crystals. Conversely, when the lapse rate is large the melting occurs more rapidly and, correspondingly, a shallower layer is required to completely melt the ice crystals. This is something to keep in mind when assessing the depth of a surface based warm layer, particularly in those marginal cases when the depth of the layer is between 750 and 1500 feet.

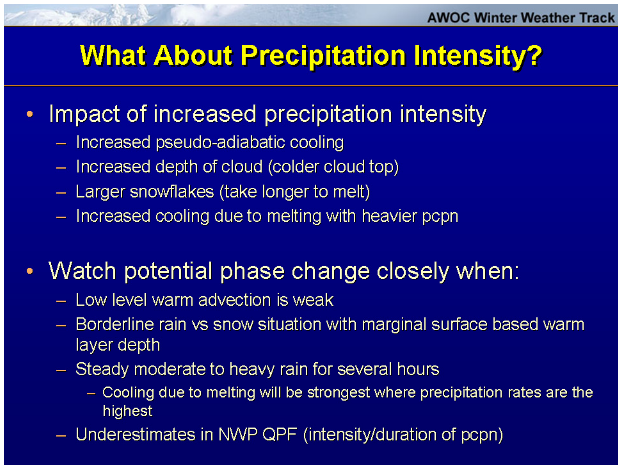
Student Notes:



26. What About Precipitation Intensity?

Instructor Notes: Another aspect that we must keep in mind is the impact of precipitation intensity. It is not uncommon to see a borderline rain versus snow event in which the precipitation type changes to snow in locations that are experiencing heavier precipitation rates. Increased precipitation intensity has several impacts that may result in the precipitation changing from rain to snow in these marginal cases. Increased precipitation intensity is associated with enhanced vertical motion which will lead to greater pseudo-adiabatic cooling. Heavier precipitation rates would also typically be associated with deeper cloud depths which may allow the cloud top to extend to regions that support heterogeneous nucleation. Other impacts include the potential for larger snowflakes which take longer to melt and increased cooling associated with the melting of these larger flakes. While no explicit rules exist this concept is something to keep in mind when making forecasts in marginal rain versus snow situations. Watch for the potential for rain to change to snow due to cooling in the surface based melting layer in the following scenarios: 1) Low level warm advection is weak, 2) You are dealing with a borderline rain versus snow scenario due to the depth of a surface based melting layer, and 3) Steady moderate to heavy rain for several hours. A heavier precipitation rate such as would be expected in this scenario requires significant melting in the surface based layer which can ultimately lead to column cooling changing the precipitation to snow. - If NWP guidance significantly underestimates the amount precipitation (i.e., intensity and duration of precipitation) it may not correctly assess the potential for column cooling.

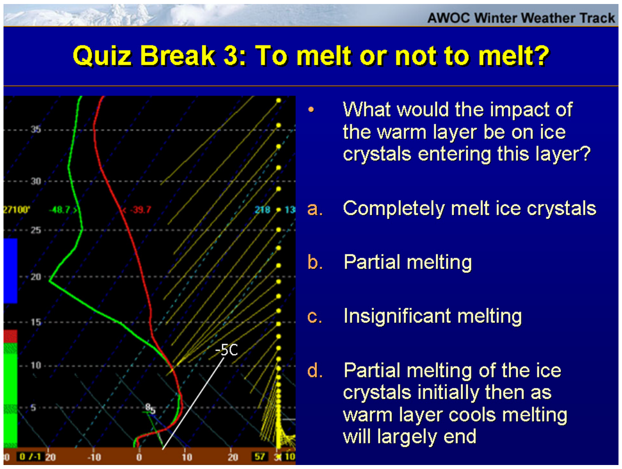
Student Notes:



27. Quiz Break 3: To Melt or Not to Melt?

Instructor Notes: Assume that you have ice crystals entering the warm layer in this BUFKIT example. What would the impact of the warm layer be on ice crystals entering this layer? Advance to the next slide when you are ready to hear the answer.

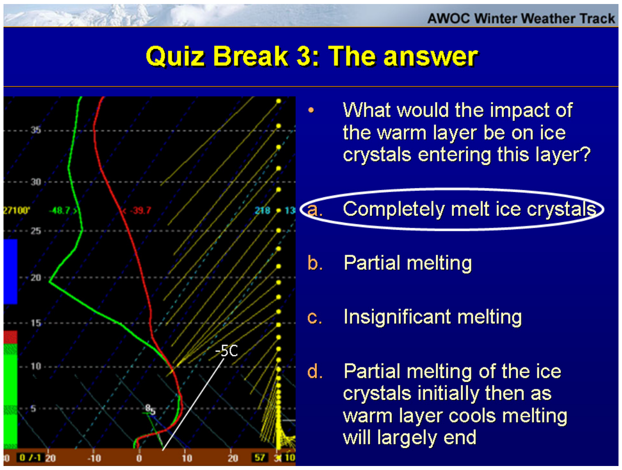
Student Notes:



28. Quiz Break 3: The Answer

Instructor Notes: The Max T in the warm layer is +4 degrees C and given what we reviewed earlier in the module this should be enough to completely melt the ice crystals. Assuming that we have ice crystals entering the layer, which is very near saturation through the entirety of its depth, and the surface based layer is sub-freezing all the way to the ground, I would expect freezing rain.

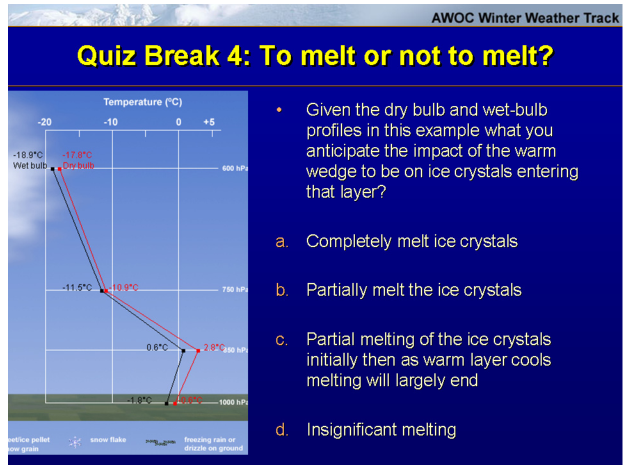
Student Notes:



29. Quiz Break 4: To Melt or Not to Melt?

Instructor Notes: Given the dry-bulb and wet-bulb profiles in this example what you anticipate the impact of the warm wedge to be on ice crystals entering that layer? Click to the next slide when you are ready to hear the answer.

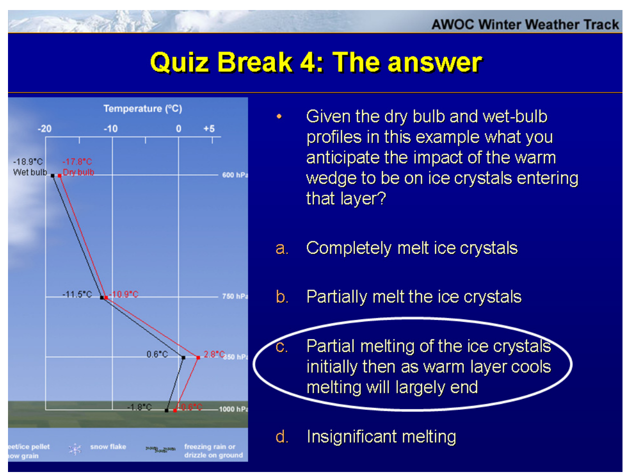
Student Notes:



30. Quiz Break 4: The Answer

Instructor Notes: Initially as ice crystals enter this warm layer, the most reasonable expectation is for the ice crystals to nearly completely melt. However, given that the warm layer is not saturated we would anticipate evaporative cooling to occur as the ice crystals fall through this layer. The max temperature in the layer will cool to the wet-bulb temperature which is +.6 degrees C. This temperature will not be warm enough to result in substantial melting of the ice crystals (unless it occurred over an abnormally deep layer). Therefore the correct answer in this case is c. Initially the ice crystals will likely nearly completely melt then as the warm layer cools the melting will largely end.

Student Notes:



31. Components of Top-Down Methodology

Instructor Notes: This is a review of the slide that was presented near the beginning of this module. We have covered each of the components from the likelihood of ice in the cloud, to the warm layer impacts, surface layer considerations, and ancillary topics such as the seeder-feeder mechanism and wet bulb impacts. We will now attempt to bring the whole process together in a step-by-step manner.

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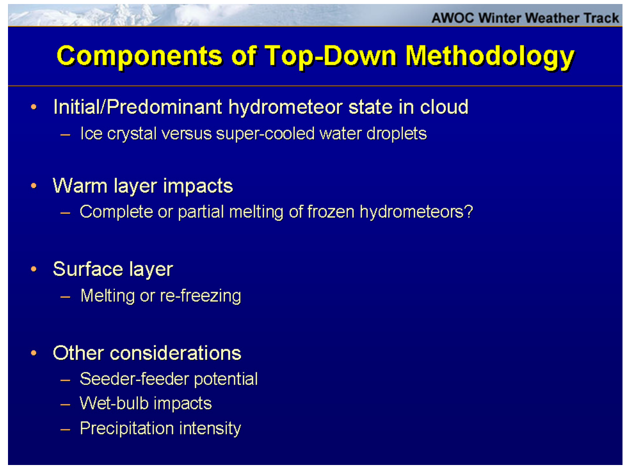

32. Top-Down Method – Top Level

Instructor Notes: The top-down method begins with a determination as to the potential presence of ice crystals in the cloud. To complete this initial step we will look at the upper reaches of the cloud to determine if ice crystals will likely be present. If the cloud top temperatures are -4C or warmer it can be assumed that ice crystals are not present in the cloud (assuming no seeder-feeder process in place). If cloud temperatures are colder than -10 degrees C it is assumed that ice crystals will likely be present in the cloud as there is at least a 50% chance of ice crystals being present. By the time cloud top temperatures reach -15 degrees C it is highly likely that ice crystals are present. So, the initial determination is whether or not ice crystals will be present in the cloud for the time frame of concern. Once you have determined this we will assess the presence of any elevated warm layers.

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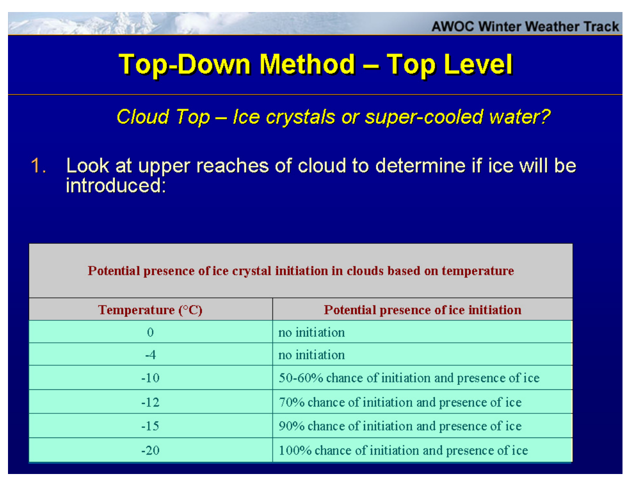

33. Top-Down Approach – Midlevels

Instructor Notes: The second step in the Top-Down methodology is to determine if there is an elevated warm layer. If not, and ice crystals are present then you can simply move on to assess the surface layer. If ice crystals are entering an elevated warm layer then you must address the degree of melting that will take place in this warm wedge. If the maximum temperature in the warm layer is less than +1 degrees C then the precipitation should remain as ice crystals, i.e., snow as it exits the layer. If the maximum temperature in the warm layer is between +1 to +3 degrees C then we can assume that partial melting will occur. Finally, if the maximum temperature in the warm layer is greater than +3 degrees C then you can assume that the ice crystals will completely melt with liquid precipitation exiting the bottom of the warm layer.   When you assess a warm layer it is important that you consider wet-bulb effects on the strength of the warm layer. In other words, if there is a strong warm wedge, but it is relatively dry in this layer, consider how much cooling will occur in this layer as a result of evaporative cooling. For example, based on the maximum temperature in the elevated warm layer we may initially anticipate the complete melting of the ice crystals as they fall through this layer. However, if the layer is initially dry, as evaporative cooling occurs the elevated warm layer may no longer support substantial melting depending on the wet-bulb temperature of the layer.

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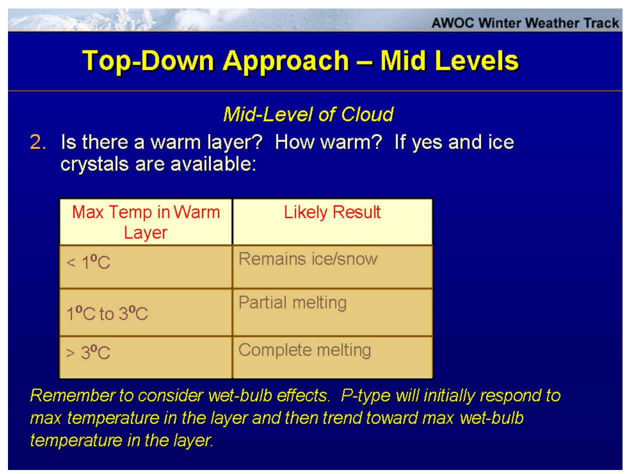
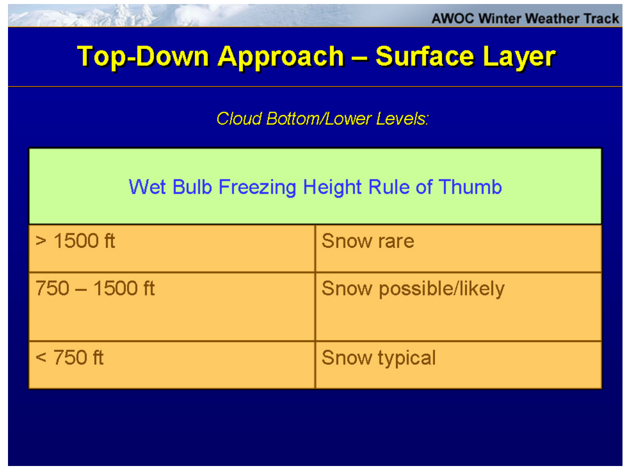


34. Top-Down Approach – Surface Layer

Instructor Notes: Finally, we will assess the lower levels of the thermal profile. Let's assume that we have ice crystals entering the lower levels of the profile.   In this evaluation of the near surface layer we will address the wet-bulb temperature. If ice crystals are entering this lowest layer and the wet-bulb temperature is very near 0 degrees C or colder down to the surface then assume the precipitation type will be snow. However, if the Tw is warmer than 0 degrees C above the surface and the surface Tw is > 1.5 degrees C then Rain or a mix of Rain and Snow is possible.   If we have a mix entering this lowest level (i.e., the elevated warm layer is between +1C and 3 degrees C) and the wet-bulb temperature or ambient air temperature is less than 0 degrees C the particle will immediately refreeze to form ice pellets at the surface. This occurs because the crystal only partially melted leaving an ice embryo at it's center which can quickly initiate freezing in a sub-zero layer. However, if a mix is entering the near surface layer and the Tw is near or above 0 degrees C and the surface Tw is greater than 1.5 degrees C then expect rain. We can also assess the depth of a surface based warm layer by looking at the height of the wet-bulb zero. If the wet-bulb zero height is > 1500 ft. then snow is unlikely while if the wet-bulb zero is less than 750 feet snow is quite likely. In marginal cases we must also consider the precipitation rates.

Student Notes:



35. Top-Down Approach – Surface Layer

Instructor Notes: Finally, let's consider what would occur with supercooled water droplets entering the lower levels. If the minimum temperature in the near surface layer is warmer than -10 degrees C and the surface wet-bulb temperature is 0 degrees C or less then you would anticipate freezing drizzle or freezing rain depending on the droplet size. If supercooled water is entering a low level profile in which the minimum temperature is warmer than -10 degrees C and the surface wet-bulb temperature is warmer than 0 degrees C you would anticipate rain or drizzle.   Finally, if supercooled water enters a near surface layer in which the minimum temperature is less than -10 degrees C and the surface wet-bulb temperature is less than 1.5 degrees C you can expect snow and sleet.

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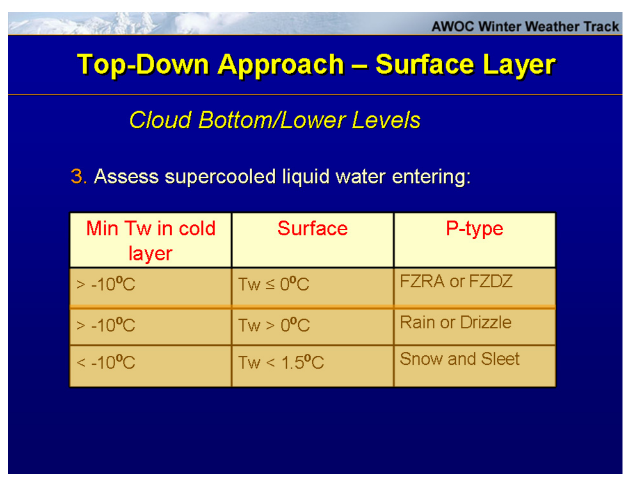
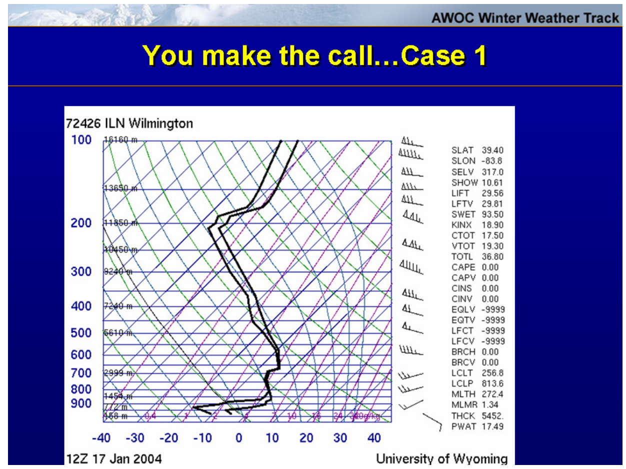


36. You Make the Call…Case 1

Instructor Notes: Make an assessment of p-type for this sounding. Click on the next button when you are ready for the answer.

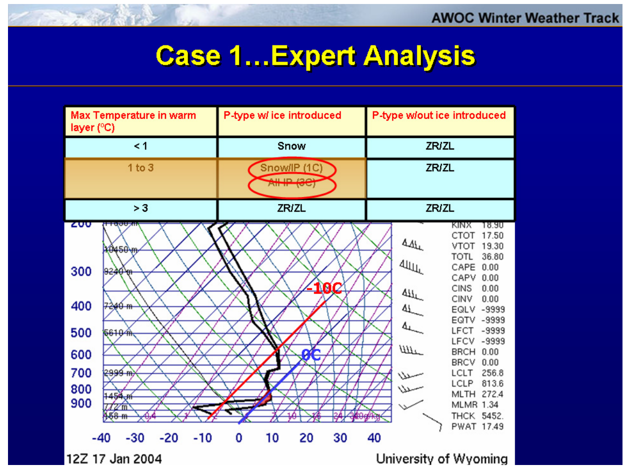
Student Notes:



37. Case 1…Expert Analysis

Instructor Notes: In this example, we see that saturation extends to temperatures well below -10 degrees C. In fact, it is saturated to around -20 degrees C so we can have very high confidence that ice crystals will be present in the cloud. The warm layer assessment is more intriguing. Note that the max temperature in the warm layer is between +2 and +3 degrees C. Recalling the table referencing the impact of the warm layer on frozen hydrometeors we can anticipate the likely impact of the warm layer on the ice crystals. This does not look like an anomalously deep warm layer as it has the classic wedge appearance, so we can look at the expected degree melting with some confidence. Since the warm layer is between +2 and +3 degrees C we would anticipate significant, but not complete melting of the ice crystals which would lead us to believe that with a cold wedge at the surface (which is present in this case) we could then anticipate re-freezing of the hydrometeors into the form of ice pellets with possibly some snow as well. This appears to be likely at the onset given the maximum temperature in the warm layer, but what about the impact of wet-bulb effects? Note that there is separation between the temperature and dewpoint curves in the profile indicating that the layer will experience wet-bulb cooling as hydrometeors enter this layer and begin to melt. This cooling would likely occur relatively quickly with the temperature in the layer cooling to the wet-bulb temperature. With this in mind you might anticipate a period of ice pellets changing over to snow as the warm layer cools. Obviously in a situation such as this it would be prudent to mention a combination of snow and ice pellets in the forecast.

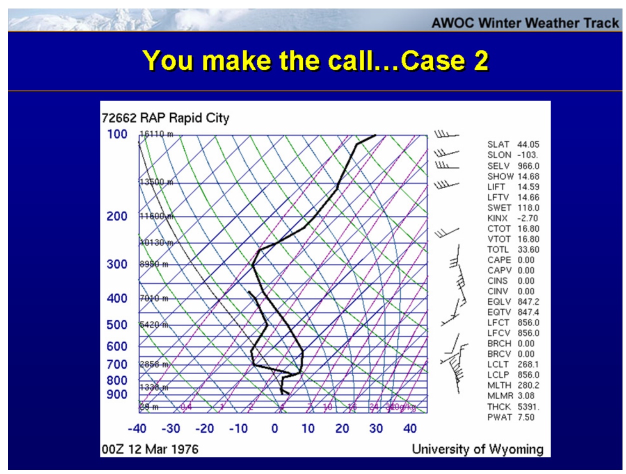
Student Notes:



38. You Make the Call…Case 2

Instructor Notes: Now, make an assessment of p-type for this sounding. Once again, when you are ready for the answer, advance to the next slide.

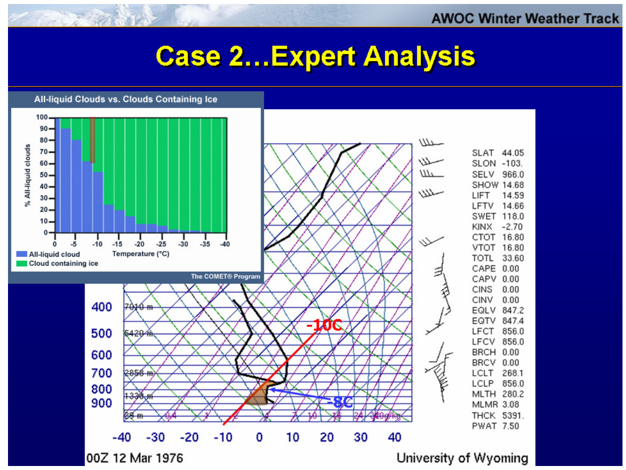
Student Notes:



39. Case 2…Expert Analysis

Instructor Notes: As usual we will start at the top and work our way down through the sounding. So, will this profile support heterogeneous nucleation? Let's first identify how cold the temperatures are in the saturated layer. We can see that the sounding is not saturated to -10 degrees C. Identifying the coldest temperature that exhibits saturation in the sounding we see that it is about -8 degrees C. Therefore, it is not likely that this cloud will support heterogeneous nucleation. However, as we discussed earlier in the module there is certainly a chance that this cloud would support heterogeneous nucleation (around 40% chance). However, the most likely outcome is that the profile will not support the initiation of ice crystals and the cloud will be populated with supercooled water droplets. Given that the cloud is most likely composed of supercooled water droplets and the surface temperature is below freezing the most probable precipitation type associated with this sounding is freezing drizzle.

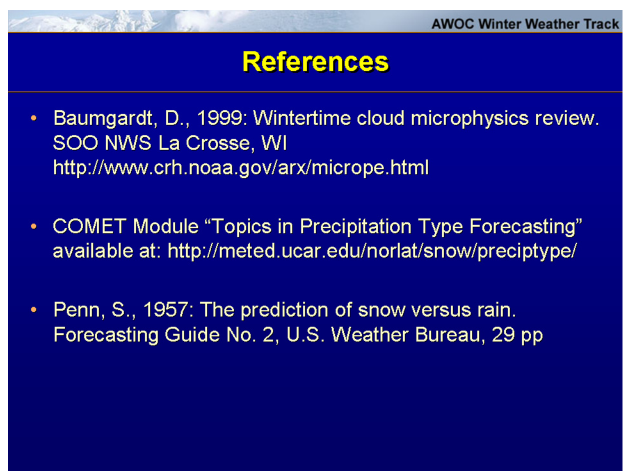
Student Notes:



40. References

Instructor Notes: Here is the first of two slides listing the references cited during the presentation.

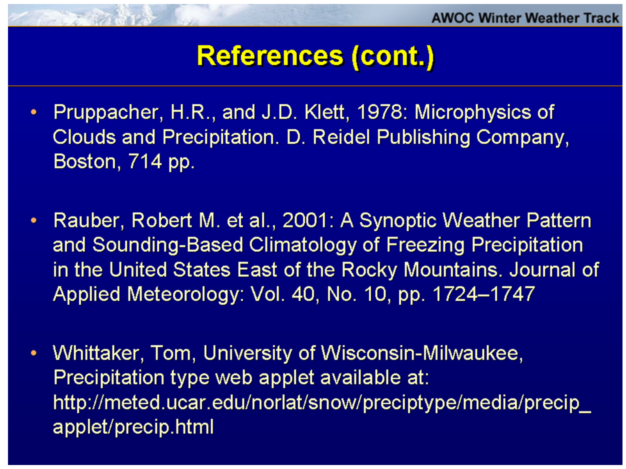
Student Notes:



41. References (Cont.)

Instructor Notes: Here is the second of two slides listing the references cited during the presentation.

Student Notes:



42. Questions???

Instructor Notes: After going through this lesson if you have any questions, first ask your SOO or your local AWOC Winter facilitator. Your AWOC facilitator should be able to help answer most questions. If you need additional info from what your SOO provided, please send an E-mail to the address on the slide. This address sends the message to the instructors who developed this IC. Our answer will be CC'd to your SOO so that they can answer any similar questions that come up in the future. We may also consider the question and answer for our FAQ page. Thanks for your time and good luck on the exam!

Student Notes: